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Still-Frame Image Transmission using DPCM/Interpolative Coding

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STILL-FRAME IMAGE TRANSMISSION USING DPCM/INTERPOLATIVE CODING†

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ABSTRACT

Two methods of combining DPCM and interpolation are proposed for compressing still-frame teleconferencing signals. The first method uses horizontal subsampling, DPCM, and interpolation to achieve a 4:1 compression. The other method is similar, but uses vertical subsampling instead. Simulation results indicate that either method can easily achieve the required 2 bits/pel data rate with negligible degradation in image quality. Conventional DPCM is shown to perform slightly better in quantitative terms when fixed word-length coding is used. However, the two DPCM/interpolation methods offer other advantages when used with a variable word-length coder.

I. INTRODUCTION

Although much research effort has been spent in recent years on developing visual teleconferencing systems with full-motion capability, techniques have also advanced in the area of still-frame (or freeze-frame) image transmission. With this type of transmission, a single frame is transmitted at a rate which is much lower than that required for full motion. This is quite satisfactory for many applications, and a significant savings in transmission cost is obtained for the subscriber.

In order to improve the efficiency (and marketability) of the still-frame concept, it seems reasonable that we should apply data compression principles if the additional hardware requirements are relatively simple. In this paper, we show that high-quality images can indeed be transmitted with negligible degradation at one-fourth their original bit rate. This is accomplished by using differential pulse code modulation (DPCM) and simple interpolative coding techniques.

In the sections that follow, we examine two methods of combining DPCM with interpolation. The first method uses 2:1 horizontal subsampling and subsequent interpolation to achieve half of the required compression. The remaining compression is obtained by applying DPCM to the subsampled picture elements (pels). The second method is similar, but uses 2:1 vertical subsampling instead. A third system consisting of DPCM only is also simulated to serve as a standard for comparing the effects of interpolation in the first two systems. Coarser quantization and a reduced codeword set are used on this third system so that each method achieves a 4:1 compression. This allows all three methods to be compared on an equal bit-rate basis.

II. DPCM WITH INTERPOLATION

DPCM has been used extensively for coding picture signals since its invention in 1952 [1]. Variations of DPCM have been developed for both intraframe and interframe coding [2]-[4], but the basic theory of operation remains the same. The concept of DPCM is illustrated in Fig. 1.

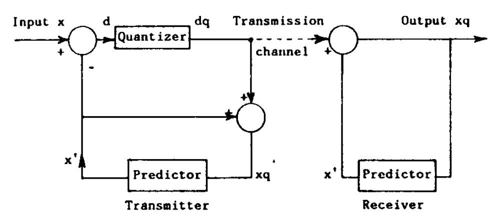

Fig. 1. Block diagram of the basic DPCM system.

Prior to the arrival of each input sample x, a prediction x' is made, based upon previously-reconstructed samples. The difference (or prediction error) d = x - x' is determined and quantized to an approximate value dq. If the prediction function is well-chosen, the difference d will be small in most parts of the picture. This means that a significant amount of redundancy has been removed from the original signal. If nonuniform quantization is used, fewer bits are needed to encode each error sample, and a bit rate reduction is achieved. At the receiver, a similar prediction loop operating in synchronism adds dq to the predicted value x'. Assuming that no errors occur during transmission, the reconstructed value xq is identical on each side.

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Combining DPCM with Interpolative Coding

DPCM can compress the amount of information to be transmitted considerably. To achieve further compression, it is proposed that interpolation be used in conjunction with DPCM. By this it is meant that the input picture element values are subsampled at a rate of 2:1 to achieve an initial 2:1 compression. A second 2:1 compression is then obtained by transmitting the subsampled pels with DPCM. At the receiver, the non-sampled pels are replaced with interpolated values obtained from adjacent subsampled pels. The overall compression rate is, therefore, 4:1.

Two different subsampling techniques are proposed for achieving the 2:1 compression. The first method is termed "horizontal" subsampling as only alternate pels in the horizontal direction are selected for transmission by DPCM. The subsampling pattern is staggered as shown in Fig. 2 so that a better interpolation can be obtained for the non-sampled pel "E". The other technique is termed "vertical" subsampling because only alternate lines are transmitted. This is shown in Fig. 3. When the picture is scanned in two fields (i.e., interlaced scanning), this techniques is also referred to as "field interpolation."

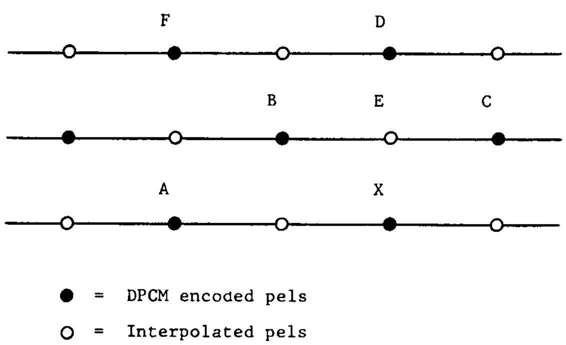


Fig. 2. Picture element configuration for DPCM with horizontal subsampling.

III. SIMULATION PROCEDURES

In order to evaluate the two proposed methods of combining DPCM with interpolation, three hypothetical systems were simulated on a VAX 11/780 digital computer. The first system used horizontal subsampling, the second system used vertical subsampling, and the third system used DPCM only. Four monochrome test images with 512 x 512 spatial resolution and an 8 bit (256 level) gray scale were used as the database. These images (shown in Fig. 4) are representative of "natural" scenes that might be transmitted on a still-frame transmission system.

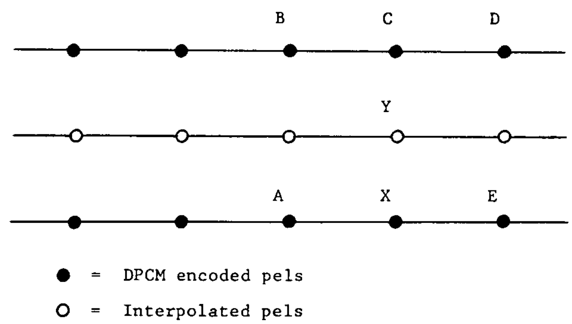


Fig. 3. Picture element configuration for DPCM with vertical subsampling.

System I - Horizontal Subsampling

For the first system, horizontal subsampling was used to achieve half of the required compression. Seven predictors were then evaluated on the basis of prediction entropy and variance to determine which predictor would be best suited to this sampling pattern. Using the notation of Fig. 2, the seven predictors are as follows:

(a) $X' = \frac{(C + A)}{2}$

(b) $X' = A + (C - B)$

(c) $X' = A + \frac{(C - B)}{2}$

(d) $X' = A$ if $|C - B| < |B - A|$

$X' = \frac{(C + A)}{2}$ otherwise

(e) $X' = C$ if $|C - B| > |B - A|$ and $|D - A| < |C - B|$

$X' = B$ if $|C - B| > |B - A|$ and $|C - B| > |D - C|$

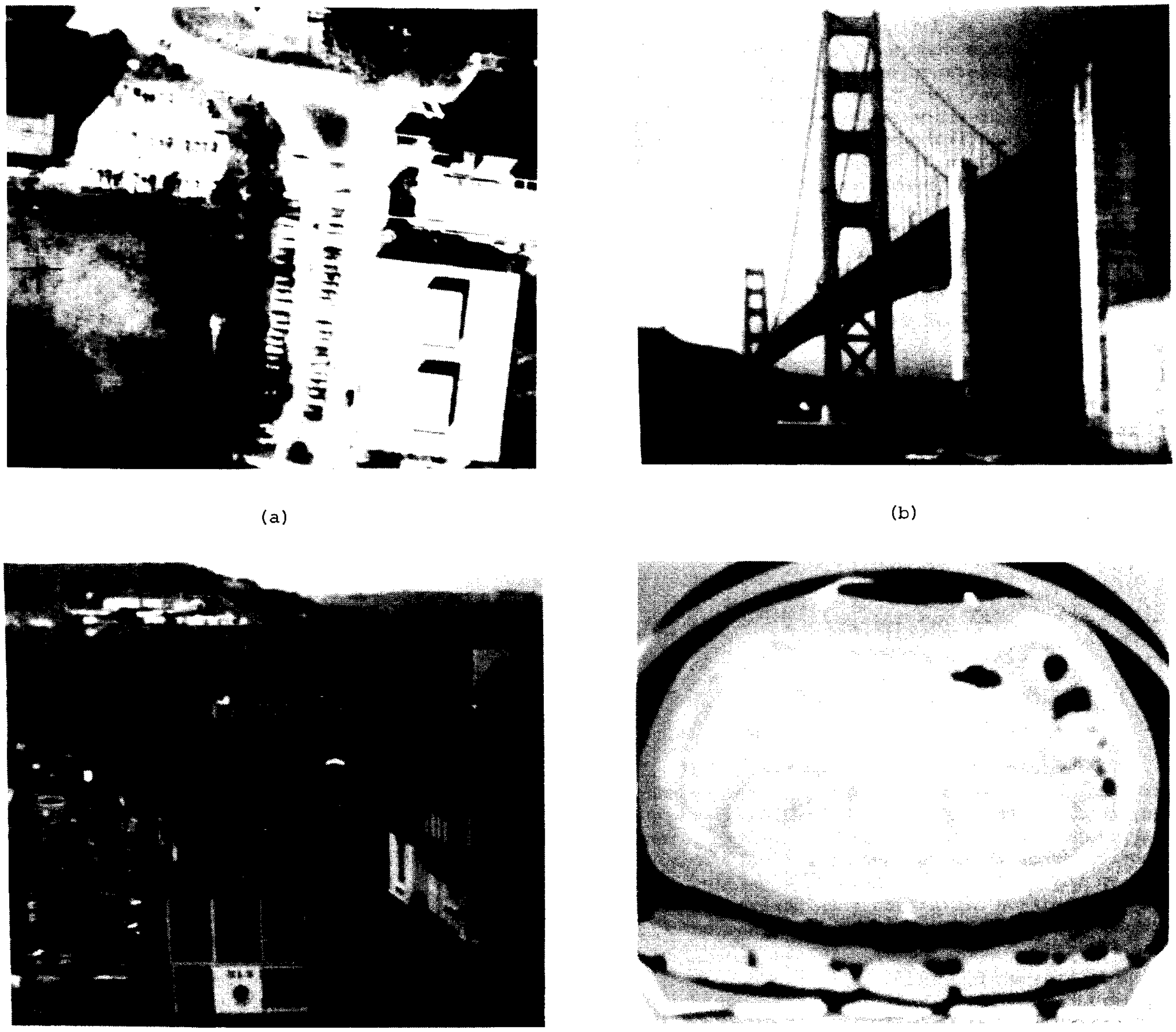
$X' = A$ otherwise

(f) $X' = \frac{(A + C)}{2}$ if $|C - B| > |B - A|$ and $|D - A| < |C - B|$

$X' = \frac{(A + B)}{2}$ if $|C - B| > |B - A|$ and $|C - B| > |D - C|$

$X' = A$ otherwise

(g) $X' = A$



(a) (b)

(c) (d)

Fig. 4. Monochrome test images used in the simulation: (a) Aerial View, (b) Bridge, (c) Cable Car, (d) Kidney.

Predictors "a", "b", and "c" were considered because they are known to perform well in picture coding applications [2]-[5]. Adaptive predictors "d", "e", and "f" were also tried since they consider possible contours in the image. Predictor "g" was included, since it is often used as a basis for comparison. The entropy and variance were computed using the following equations:

$$\text{Entropy} = -\sum_{d=-255}^{+255} \frac{N(d)}{M} \left[\log_2 \frac{N(d)}{M}\right]$$

$$\text{Variance} = \frac{1}{M} \sum_{i} \sum_{j} [d(i,j)]^2$$

where d is the prediction error,

M is the total number of pels being considered, and

N(d) is the number of pels that have d as their prediction error.

The mean of d is assumed to be zero.

The entropy, as defined here, indicates the theoretical minimum number of bits required to transmit each difference value without loss of information. The variance is an indication of the spread of the difference signal value, and hence, the resulting quantizing noise. Since we generally want to minimize both of these quantities, the predictor having the lowest values of entropy and variance was selected for use in this first system. A four bit (15 level) quantizer was then designed using the statistics that resulted from this predictor [5]. The iterative procedure suggested by Max [6] was used, so that the mean-square error in the final picture would be minimized.

To complete System I, three interpolation algorithms were evaluated on the basis of the resulting mean-square error (MSE). Referring to Fig. 2, the interpolators considered are as follows:

(a) $E = \frac{B + C + D + X}{4}$

(b) $E = \frac{B + C}{2}$ if $|D - X| > |C - B|$

$E = \frac{D + X}{2}$ otherwise

(c) $E = \frac{B + C}{2} + \frac{D - F}{2}$

Interpolator "a" is simply an average of the surrounding pel values. Interpolator "b" is adaptive, choosing the best of two possible averages. Interpolator "c" is an attempt to register reconstruction error in an oblique direction. This is based on the fact that the human eye is less sensitive to oblique distortion than horizontal or vertical distortion [7]. The MSE was calculated as follows:

$$MSE = \frac{1}{N^2} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} [g(i,j) - f(i,j)]^2$$

where $g(i,j)$ is the interpolated pel value

$f(i,j)$ is the original pel value, and

N is the number of rows or columns of the image array.

System II - Vertical Subsampling

For simulating DPCM with vertical subsampling, alternate lines were sampled and used as inputs. Only four predictors were evaluated for this system as the ones defined previously were for alternate horizontal sampling and are not applicable. Referring to Fig. 3, the four predictors are as follows:

(a) $X' = A$

(b) $X' = \frac{(A + D)}{2}$

(c) $X' = A + \frac{(C - B)}{2}$

(d) $X' = A$ if $|C - B| < |B - A|$

$X' = \frac{(C + A)}{2}$ otherwise

A four bit (15 level) Max quantizer was again designed for the predictor having the lowest overall entropy and variance. Two interpolation algorithms were considered, and the one with the lower MSE was selected for use in System II. Referring to Fig. 3, the two interpolation algorithms are as follows:

(a) $Y' = \frac{(C + X)}{2}$

(b) $Y' = \frac{(E + B)}{2}$ if $|E - B| < |X - C|$ and $|E - B| < |A - D|$

$Y' = \frac{(A + D)}{2}$ if $|A - D| < |X - C|$ and $|A - D| < |E - B|$

$Y' = \frac{(C + X)}{2}$ otherwise.

System III - DPCM Only

In order to determine the effect of interpolation in Systems I and II, a third system which used DPCM only was also simulated. The four predictors used in developing System II were also used in this system, but with pel locations as shown in Fig. 5. The best predictor was again selected, and DPCM was simulated using a 2 bit (3 level) Max quantizer. This was done so that all three systems could be compared on an equal bit rate (2 bits/pel) basis.

IV. SIMULATION RESULTS

The variance and entropy values for the predictors of System I are given in Tables I and II, respectively. It can be seen that predictor "a" results in the best performance by yielding lowest values of entropy and variance for three of the four test images. It is also observed that the aerial view resulted in much higher variance and entropy values when compared with the other test images. This is due to the fact that the aerial view had already been digitally enhanced to improve contrast and edge detail. Unfortunately, such processes also enhance noise levels in the image, and this makes the encoding task much more difficult.

Table III shows the MSE that results from the three interpolators of System I. It is clear that interpolation algorith "b" performs the best in almost every case by having the lowest MSE. In summary, predictor "a" and interpolator "b" offer the best overall choice for System I.

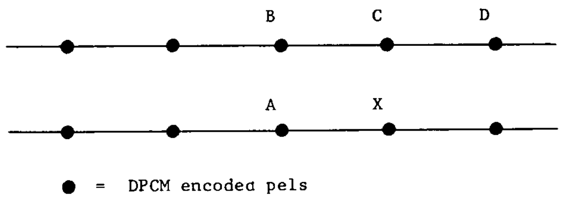


Fig. 5. Picture element configuration for DPCM only.

Table I. VARIANCE OF DIFFERENT PREDICTORS FOR DPCM WITH HORIZONTAL SUBSAMPLING

Predictors used	Aerial view	Bridge	Cable car	Kidney
Pred a	202.760554	29.192972	37.590634	6.425313
Pred b	466.559577	62.828858	77.681338	3.238616
Pred c	352.624391	57.538670	69.379077	9.032795
Pred d	330.067343	55.052649	68.388874	10.222676
Pred e	414.753149	76.456540	93.253856	11.119377
Pred f	364.021361	68.243406	82.722153	13.693110
Pred g	476.721930	103.014641	120.542537	27.413787

Table II. ENTROPY OF DIFFERENT PREDICTORS FOR DPCM WITH HORIZONTAL SUBSAMPLING

Predictors used	Aerial view	Bridge	Cable car	Kidney
Pred a	5.428469	4.113105	4.211110	2.797627
Pred b	5.959426	4.670831	4.646663	2.387959
Pred c	5.753652	4.476286	4.426804	2.911389
Pred d	5.608955	4.355070	4.362170	2.884233
Pred e	5.699670	4.653057	4.603885	2.946953
Pred f	5.638060	4.478164	4.448556	3.109401
Pred g	5.720952	4.732645	4.675528	3.422739

Table III. MSE OF INTERPOLATION ALGORITHMS FOR DPCM WITH HORIZONTAL SUBSAMPLING

Interpolation algorithm used	Aerial view	Bridge	Cable car	Kidney
Int a	48.273753	5.116126	8.426440	0.733202
Int b	48.419932	4.138976	5.083495	0.304107
Int c	112.515478	19.678292	22.929026	6.180562

The variance and entropy for the four predictors of System II are given in Tables IV and V, respectively. Of the four predictors, "c" is seen to have the lowest values in almost every case. The MSE values for the two interpolators of System II are shown in Table VI. Interpolator "a" is seen to yield the lowest MSE for all four images. In summary, predictor "c" and interpolator "a" offer the best performance for System II.

The overall variance and entropy values for the four predictors of System III are shown in Tables VII and VIII, respectively. Of the four predictors, "c" is seen to yield the lowest values for three of the four test images.

Table IV. VARIANCE OF DIFFERENT PREDICTORS FOR DPCM WITH VERTICAL SUBSAMPLING

Predictors Used	Aerial View	Bridge	Cable Car	Kidney
Pred a	186.269435	36.640292	38.922584	7.205213
Pred b	209.750865	26.240161	42.677432	14.503722
Pred c	135.587051	17.459193	18.901176	2.814141
Pred d	142.633203	18.581845	21.216894	5.530773

Table V. ENTROPY OF DIFFERENT PREDICTORS FOR DPCM WITH VERTICAL SUBSAMPLING

Predictors Used	Aerial View	Bridge	Cable Car	Kidney
Pred a	5.093724	4.098471	4.041777	2.595084
Pred b	5.442654	4.048937	4.356516	3.228649
Pred c	5.195002	3.822497	3.810371	2.256461
Pred d	5.088700	3.829263	3.848391	2.487924

Table VI. MSE OF INTERPOLATION ALGORITHMS FOR DPCM WITH VERTICAL SUBSAMPLING

Interpolation algorithm used	Aerial view	Bridge	Cable car	Kidney
Int a	82.259862	10.921130	33.389173	2.679839
Int b	107.457893	12.942630	36.773710	2.624637

Table VII. VARIANCE OF DIFFERENT PREDICTORS FOR SYSTEM III (DPCM ONLY)

Predictors used	Aerial view	Bridge	Cable car	Kidney
Pred a	186.224978	33.490882	38.498336	7.160850
Pred b	120.344077	12.814546	18.718587	4.000081
Pred c	94.133322	13.107300	14.371143	2.430090
Pred d	105.311483	14.245144	16.127154	3.875777

Table VIII. ENTROPY OF DIFFERENT PREDICTORS FOR SYSTEM III (DPCM ONLY)

Predictors used	Stadium	Bridge	Cable car	Kidney
Pred a	5.083307	4.087445	4.033582	2.595057
Pred b	5.086992	3.665172	3.861451	2.508487
Pred c	4.915267	3.667712	3.647595	2.216866
Pred d	4.884437	3.676321	3.690876	2.319404

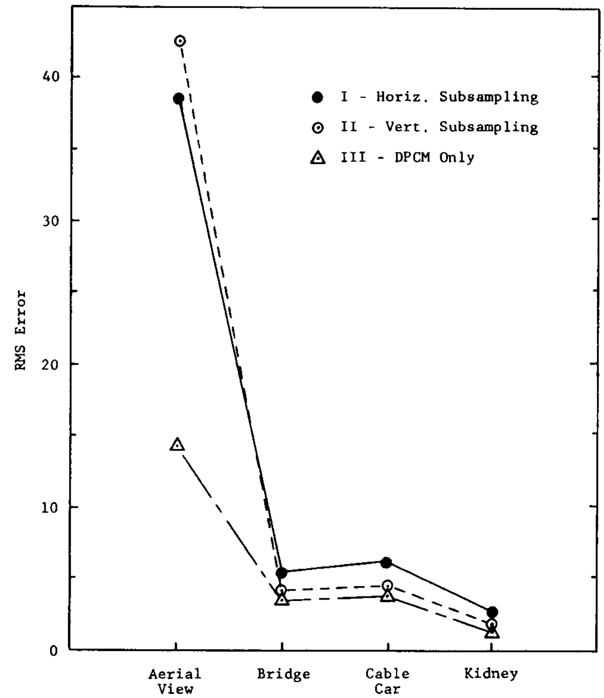


Fig. 6. Comparative performance of the three systems on the basis of RMS error.

Comparative Performance

The "best" predictor-interpolator combinations were used to simulate and finally evaluate the three systems. When compared quantitatively, System III (DPCM Only) appeared to perform the best. In Fig. 6, for example, it is seen that System III resulted in the lowest overall root-mean-square (RMS) error for all of the test images. When evaluated subjecively, no difference in image quality could be detected with either System II or System III. A slight amount of horizontal blurring was caused by System I, however, in the case of the "Bridge" and "Cable Car" scenes.

V. CONCLUDING REMARKS

For the modest 4:1 compression requirement of this experiment, it would seem that there is really no advantage in employing additional interpolation hardware. This is probably a fair statement if fixed word-length coding is used and it the input pictures are confined to "natural" scenes. If variable word-length coding were to be used, Systems I and II would result in lower bit rates with essentially the same picture quality. This is due to the fact that the prediction error entropy in all cases is about the same for all three systems. In the case of System III, however, there are twice as many DPCM samples for each frame. If the interpolation errors are small, the bit rates for Systems I and II would be approximately half of that required for System III. In the case of System I, the A/D converter could also operate at half the speed.

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